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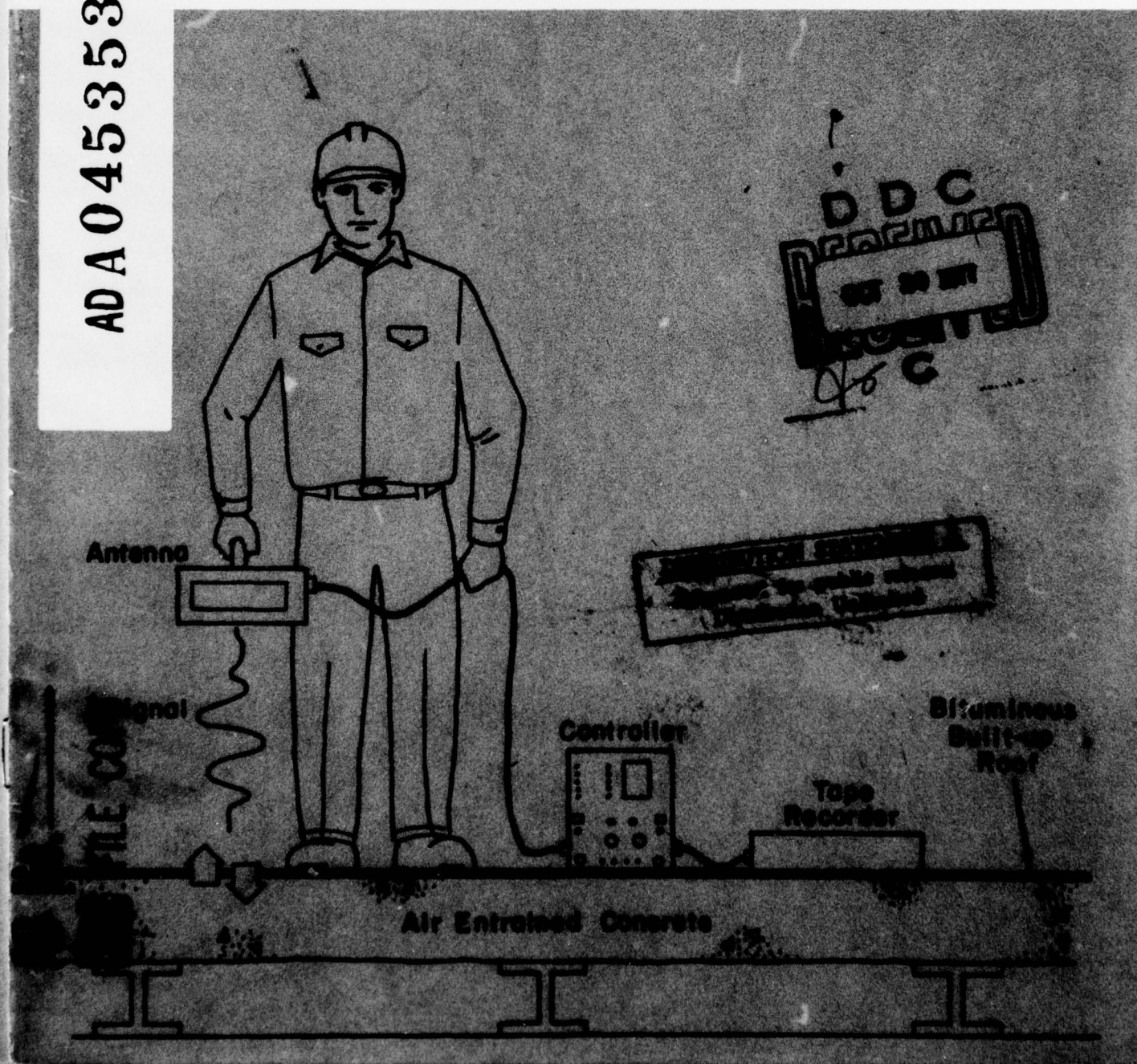
# CRREL

## REPORT 77-25



*Detection of moisture in construction materials*

AD A 045353



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## *Detection of moisture in construction materials*

Rexford Morey and Austin Kovacs

September 1977.

Prepared for

DIRECTORATE OF MILITARY CONSTRUCTION  
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Results of a study to determine the feasibility of using an impulse radar to detect moisture variations in the built-up roof at CRREL and to monitor the curing of concrete are presented. The results indicate that impulse radar can be used to detect wide variations in roof moisture associated with built-up roof surface deterioration and that this technique has the potential of providing a nondestructive test method for measuring the strength of concrete during curing.		

## PREFACE

This report was prepared by Rexford Morey, Director of Research and Development, Geophysical Survey Systems, Inc., Hudson, New Hampshire, and Austin Kovacs, Research Civil Engineer, Foundations and Materials Research Branch, Experimental Engineering Division, CRREL.

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**CONVERSION FACTORS: U.S. CUSTOMARY TO METRIC (SI)  
UNITS OF MEASUREMENT**

These conversion factors include all the significant digits given in the conversion tables in the ASTM *Metric Practice Guide* (E 380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E 380).

<i>Multiply</i>	<i>By</i>	<i>To obtain</i>
inch	0.0254*	meter
foot	0.3048*	meter
pound/inch <sup>2</sup>	6894.757	pascal

\* Exact

## DETECTION OF MOISTURE IN CONSTRUCTION MATERIALS

Rexford Morey and Austin Kovacs

### INTRODUCTION

A nondestructive method is needed to measure the moisture content of construction materials such as air-entrained cement insulation and rigid plastic insulation. Moisture within these materials adversely affects their strength and insulating properties. An example of this is the effect of moisture in the low-density closed-cell rigid urethane or polystyrene and air-entrained cement used as insulation in roofs. Schaefer (1976) points out that the failure of roofing systems in cold regions has been a fact of life for years and that in Alaska failure rates for conventional bituminous built-up roofs exceed 70%. When failure occurs in the bituminous layer, moisture can enter and permeate into the underlying material. Subsequent freeze-thaw cycles cause further deterioration of the bituminous overlay and moisture migration into the underlying insulation. As a result, the effectiveness of the insulation deteriorates.

A nondestructive method is also needed to monitor the strength of concrete during curing to ascertain as soon as possible the projected strength of the material. Concerning this problem, Popovics (1975) states: "With the increasing speed of construction, the larger volumes of concrete that are now placed at one time, and the emphasis on quality control, the need for factual evidence of the suitability of the concrete at the earliest possible stage becomes increasingly important."

Similarly, Forrester (1975) explains: "The quality of concrete is tacitly accepted when it is placed in a structure, and its cost in terms of the cost of its replacement increases rapidly with time from placement. This increase in cost, which is demonstrated when there is a fault in the concrete quality, arises from the inevitable delay and disorganization of construction, the discussion and attempts at reappraisal which may involve additional testing, and the increasing

difficulty of replacement. It is therefore obvious that rapid assessment of concrete quality can provide data for an immediate engineering decision on the fate of the concrete and effect savings in cost."

The ultimate strength of concrete is influenced by the water added to the mix, absorbed water in the aggregate used, setting time, weather conditions, temperature, cement formulation and other relevant factors governing the physical state of the water in the concrete. Therefore, by monitoring the free moisture content in concrete during curing, it may be possible to ascertain its strength with time and to predict its ultimate strength during initial curing.

This report presents the results of a study to determine the feasibility of using electromagnetic sounding with an impulse radar system to detect relative moisture variations in air-entrained cement roof insulation and in concrete during curing.

### IMPULSE RADAR SYSTEM

An impulse radar system for investigating solid earth materials such as ice, rock and soil has been developed by Geophysical Survey Systems, Inc. (GSSI). The equipment functions as an echo-sounding system using electromagnetic (EM) impulses of only a few nanoseconds duration. The primary quantity measured is the difference in travel time between various echoes. The system consists of timing electronics which clock an impulse generator and sampling head, and various recording equipment, such as a magnetic tape recorder.

Different types of antenna/transceiver units can be used with the basic timing and recording equipment. For the experiments described in this report, a very small antenna unit (5 in. x 9 in. x 14 in.) was fabricated. The transmitter (or impulse source) generates a gaussian-shaped impulse with a peak voltage level



of about 15 V and a time duration of 0.75 ns at the half-power points. The radiated wavelet consists of 1 cycle of 1.6 ns duration, indicating a center frequency of 625 MHz and an estimated frequency spectrum from 375 to 875 MHz at the -3db points.

Besides measuring the travel time between two reflecting interfaces, the amplitude of the reflected signal provides additional information about the material being probed. Since impulse radar is similar to time domain reflectometry (TDR) (Fellner Feldegg 1972), the radar data can be analyzed using certain TDR formulas. As an example, the dielectric constant can be calculated using two different formulas:

$$\epsilon_r = \left( \frac{1 - \rho_1}{1 + \rho_1} \right)^2 \quad (1)$$

where  $\epsilon_r$  = dielectric constant

$\rho_1$  = reflection coefficient of first reflection  
( $\rho = -1$  for a perfect reflector, e.g., a metal sheet).

Conversely, the reflection coefficient  $\rho_1$  at the air/material interface is a function of the material interface dielectric constant:

$$\rho_1 = \left( \frac{1 - \sqrt{\epsilon_r}}{1 + \sqrt{\epsilon_r}} \right) \quad (2)$$

When a second reflective interface exists, the reflection coefficient  $\rho_2$  must be corrected for the partial reflection of the EM-pulse energy at the first air/material dielectric interface using:

$$\rho'_2 = \rho_2 (1 - \rho_1^2) \quad (3)$$

where  $\rho'_2$  = corrected reflection coefficient.

The second method for calculating the dielectric constant is by measuring the two-way travel time of the EM impulse between the top and bottom interfaces of the material being sounded. The bulk or effective dielectric constant  $\epsilon'$  of the material is calculated by:

$$\epsilon' = \left[ \frac{(t/2)c}{\ell} \right]^2 \quad (4)$$

where  $t$  = two-way travel time from surface to and from subsurface interface, ns

$c$  = velocity of EM impulse in air = 0.9843 ft/ns = 11.81 in./ns

$\ell$  = thickness, in.

For many materials, both natural and man made, the EM impulse velocity of propagation and the reflection coefficient are strongly influenced by free water in the material. Therefore, measured variations in these EM impulse parameters are an indication of changes in moisture within the material.

## RESULTS AND DISCUSSION

The impulse radar was set up on the roof at CRREL on 8 September 1976, and measurements were made at six sites (Fig. 1). Cores were taken at stations C and D several days prior to the radar measurements and the moisture content of the samples was determined. Several days after the radar measurements were made, cores were taken at the other four stations (A, A', B and E). The antenna was supported 21½ in. above the roof surface. Before measurements of the radar impulse reflected from the roof surface were made, a 3-ft-square aluminum sheet was placed on the roof under the antenna. The reflected radar impulse from the aluminum sheet was used to calibrate the radar system.

The radar data were recorded on a magnetic tape recorder and later transferred to an X-Y plotter for display and analysis. Figure 2 shows an X-Y plot of the reflected signal from the metal sheet with peak-to-peak amplitude  $A_s$ . All subsequent data were normalized to this reflection, assuming the reflection coefficient from a perfect reflector to be -1. Examples of roof reflections at station A and E are shown in Figure 3. Moisture content, "surface reflection" coefficient  $\rho_1$ , and dielectric constant  $\epsilon_r$  calculated from eq 1 are listed in Table I. A graphic presentation of moisture versus "surface reflection" coefficient data in Table I is shown in Figure 4. The results clearly show an increase in the roof "surface reflection" coefficient with moisture content.

Table I. Comparison of roof moisture content with radar "surface reflection" coefficient and dielectric constant.

Station	Moisture by weight (%)	$\rho_1$	$\epsilon_r$
B	6.2	-0.21	2.35
A'	11.8	-0.22	2.45
A	14.3	-0.26	2.90
D	19.0	-0.26	2.90
E	35.3	-0.52	10.03
C	38.0	-0.52	10.03

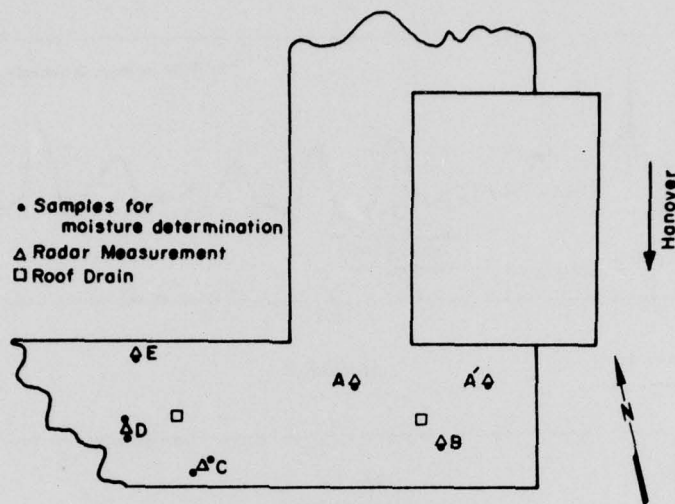


Figure 1. Relative locations where impulse radar measurements were made and samples for moisture determinations were obtained on the CRREL roof.

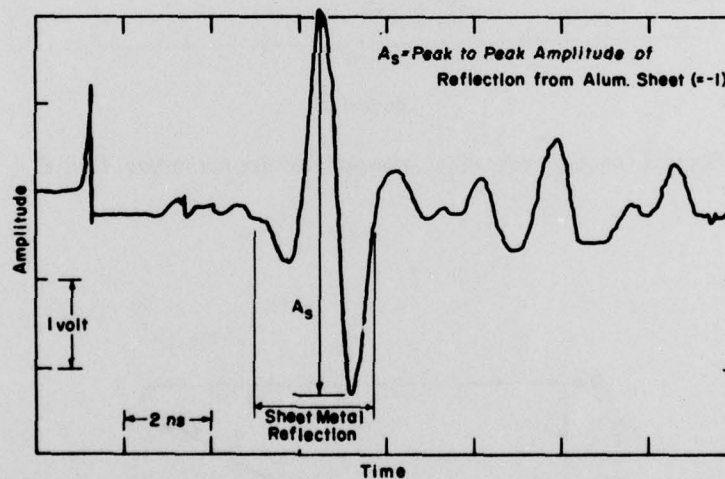
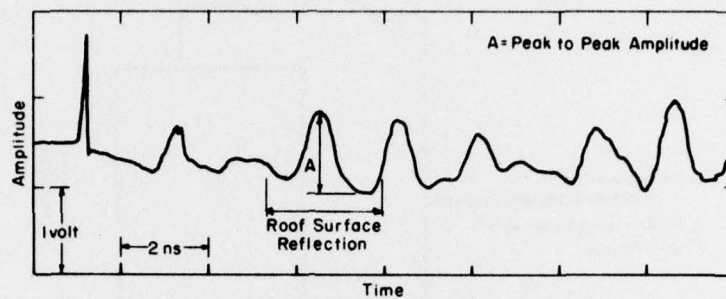


Figure 2. Impulse radar signal reflected from metal sheet resting on roof.

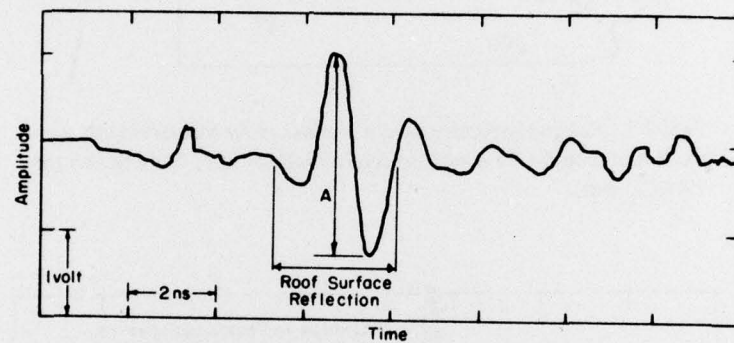
A second experiment was performed in the laboratory to monitor the curing of concrete. A plywood form 30 in. square by 5 in. deep, with aluminum foil on the bottom, was filled with a portland cement concrete mix at 1030 hours on 9 September 1976. The radar antenna was suspended 19 1/4 in. above the top of the form. Figure 5 shows the reflected signal (peak-to-peak amplitude  $A_s$ ) from an aluminum sheet set on top of the form and from aluminum foil ( $A_F$ ) on bottom of the form. Radar measurements were made periodically for the next 25 days. Strength

measurements were also made on 6-in.-diam by 12-in.-long concrete cylinders made from the same mix and cured in the same laboratory room as the test slab. A cylinder was broken every second day for 22 days. The resulting concrete strength versus elapsed time is plotted in Figure 6.

The impulse radar signal data were again recorded on a magnetic tape recorder and, when the experiment was completed, transferred to an X-Y plotter for display and analysis. Examples of four signal waveforms are shown in Figure 7. The peak-to-peak



Station A.



Station E.

Figure 3. Impulse radar signal reflection from roof at station A and E.

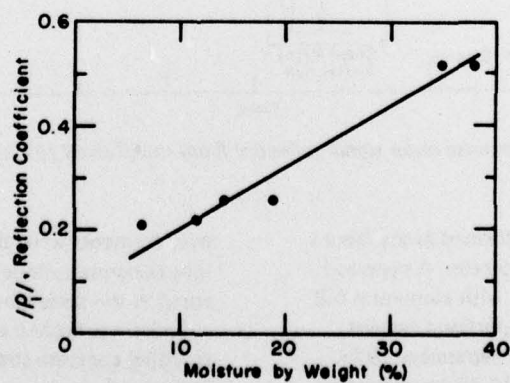
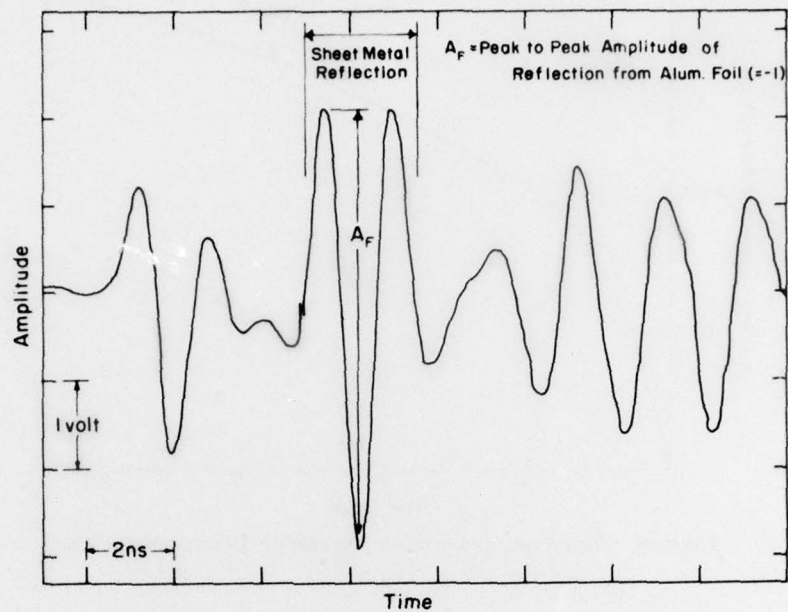
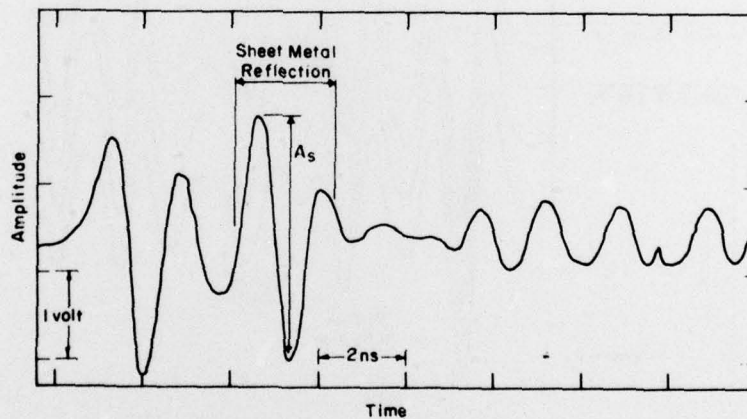


Figure 4. Impulse radar surface reflection coefficient versus moisture content of roof.





a.



b.

**Figure 5.** Impulse radar signal reflection from aluminum foil ( $A_F$ ) on bottom of concrete form and from aluminum sheet metal ( $A_S$ ) resting on top of form.

amplitudes for three wavelets on the radar signal were tabulated. The first wavelet (peak-to-peak amplitude  $A_0$ ) is the radar signal traveling through air from the transmitting to the receiving antenna and should always be constant. However, because of instrumentation drift over the 25-day period, this amplitude changed

slightly and, therefore, was used to correct the amplitude of the rest of the waveform. The second wavelet (peak-to-peak amplitude  $A_1$ ) is the reflection from the concrete surface, and the third wavelet (peak-to-peak amplitude  $A_2$ ) is the reflection from the bottom of the concrete.

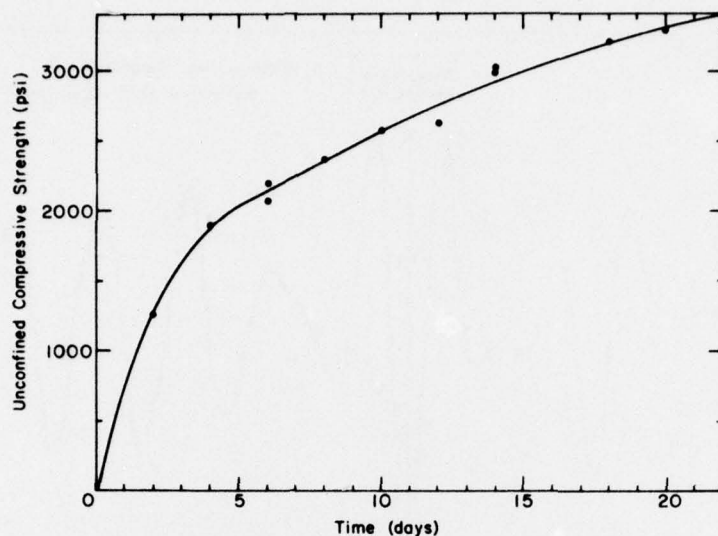


Figure 6. Unconfined compressive strength of concrete versus time.

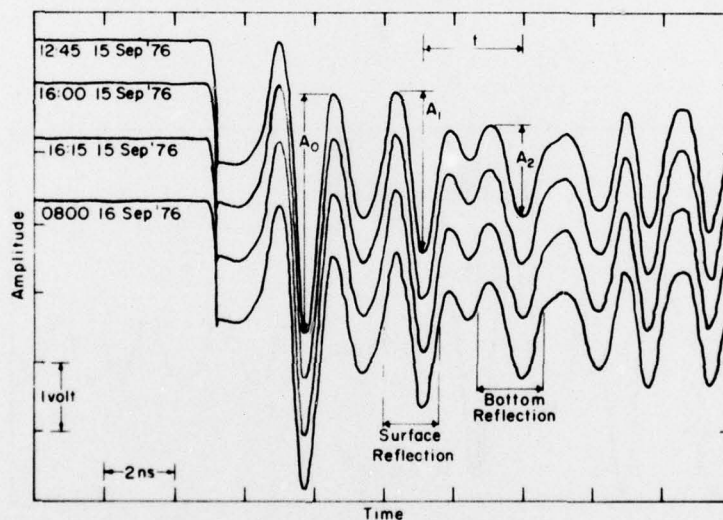


Figure 7. Examples of X-Y plots of impulse radar signals obtained during the sounding of concrete slab.

The reflection coefficient for the surface of the concrete is calculated using:

$$\rho_1 = \frac{A_1}{A_0} \times \frac{1}{(A_s/A_0)} \quad (5)$$

where  $A_s/A_0 = 1.224$ .

Likewise, the reflection coefficient for the bottom surface is calculated using:

$$\rho_2 = \frac{A_2}{A_0} \times \frac{1}{1.224} \quad (6)$$

Equation 3 was then used to correct the reflection coefficient  $\rho_2$  to  $\rho_2'$ .

A plot of reflection coefficients  $\rho_1$ ,  $\rho_2$ , and  $\rho_2'$  versus elapsed time is shown in Figure 8. For the first day  $\rho_1$  is large, indicating a high moisture content, possibly related to a thin film of water on the concrete surface. The low amplitude of the impulse

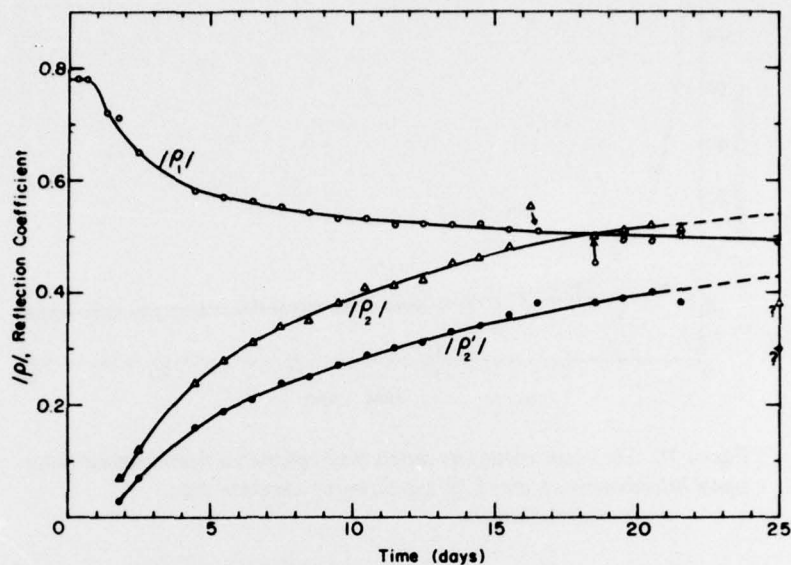


Figure 8. Impulse radar signal reflection coefficients versus time for a curing concrete slab. (? = questionable data.)

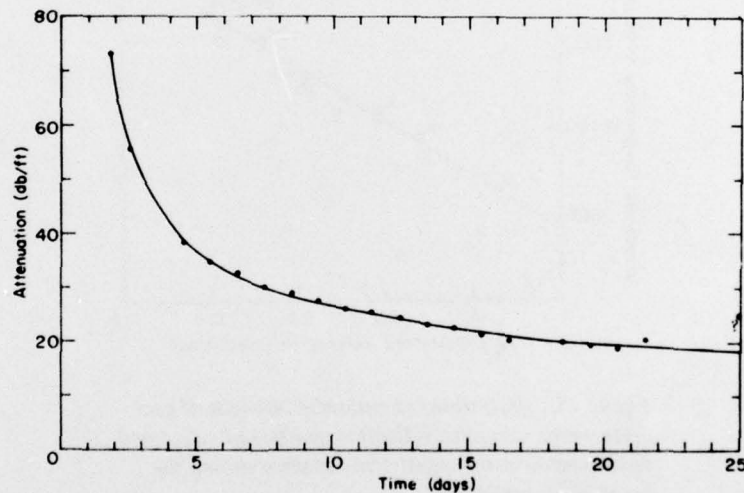


Figure 9. Calculated impulse radar signal attenuation in concrete slab versus elapsed time. (? = questionable data.)

radar reflection from the bottom of the concrete slab is an indication of losses within the slab. In fact, this signal was not discernible in the data for the first 28 hours and thus precluded determination of  $\rho_2$ . After 28 hours,  $\rho_2$  was determined and, as shown in Figure 8, became larger with time. This was due to an increase in the amplitude of the reflected signal from the bottom of the slab believed to result from a decrease in the moisture content of the concrete as the chemical curing and hardening process continued. The reason for the sudden decrease in  $\rho_2$  on the 25th and last test day is

believed to be associated with measurement error. Since  $\rho_2' = -1$  for the metal sheet regardless of the material above it,  $\rho_2'$  in Figure 8 can be used to calculate the attenuation in the concrete where:

$$|\rho_2'| \text{ (db)} = 20 \log_{10} |\rho_2'| \quad (7)$$

Figure 9 is a plot of signal attenuation in decibels/foot in the concrete slab versus elapsed time.

In a practical situation, it might not be possible to have a metal reflector on the backside of the concrete.



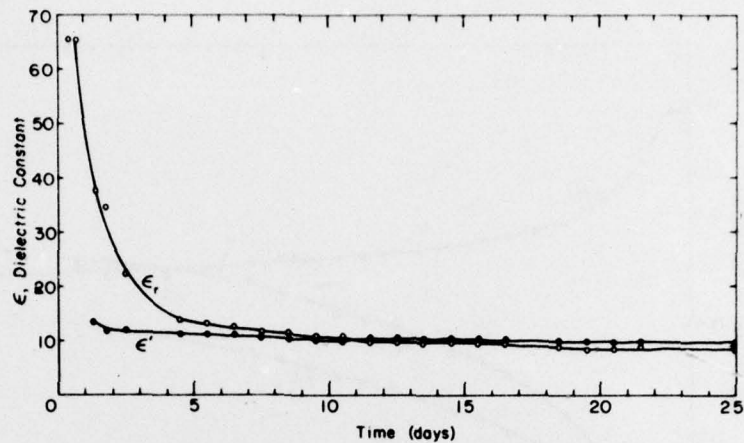


Figure 10. Dielectric constants versus time calculated from impulse radar signal information obtained during curing of concrete slab.

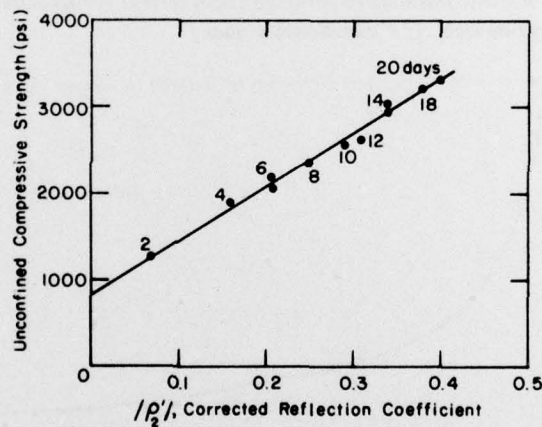


Figure 11. Unconfined compressive strength of concrete versus corrected reflection coefficient calculated from impulse radar signal data obtained during the curing of concrete slab.

If a different medium, such as air, is on the backside, then  $\rho'_2$  would be about +0.5 to +0.8, and the above analysis would still be valid except that the measured reflection coefficient would be about one-half that for a metal backing.

The two-way travel time within the concrete slab was measured from the X-Y plots and the effective dielectric constant  $\epsilon'$  calculated using eq 4. A plot of  $\epsilon'$  and  $\epsilon_r$ , as determined from eq 1, is presented in Figure 10. After the 6th day, the dielectric constant determined by these two methods agreed quite well. Before the 6th day,  $\epsilon_r$  was evidently a measure of a high surface or near-surface moisture condition. Since

the bottom reflection could not be seen during the first 28 hours,  $\epsilon'$  could not be calculated.

The most interesting result from the concrete slab impulse-radar sounding is the exceedingly good correlation between the corrected impulse radar reflection coefficient  $\rho'_2$  and the concrete unconfined compressive strength versus time. This is quite evident in the plot of unconfined compressive strength versus the corrected reflection coefficient in the first 20 days as shown in Figure 11. This correlation is encouraging, since  $\rho'_2$  is an indication of the changes in physical state of the water occurring within the concrete.

## CONCLUSIONS AND RECOMMENDATIONS

Early detection of roof deterioration associated with moisture infiltration and localization of the specific area of failure are imperative in controlling current excessive roof maintenance costs. The results of this study demonstrate that impulse radar can be used to detect variations in moisture content of built-up roofing and presumably many other materials susceptible to moisture absorption as well. The impulse radar system, however, should be modified to simplify its operation and to reduce system bulk for the specific task of moisture detection in roofs. This modification would be relatively easy to accomplish.

This study also revealed that the curing of concrete can be monitored with impulse radar and that concrete strength can be correlated with the corrected reflection coefficient determined from the impulse radar signal returning from an interface with the concrete. Further testing is necessary to verify these results and to determine if impulse radar can be reliably used as a nondestructive system for early evaluation of the strength of concrete after its placement.

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